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2020-10-10

La Mere , K M , Mäntyniemi , S & Haapasaari , P 2020 , ' The effects of climate change on Baltic salmon : Framing the problem in collaboration with expert stakeholders ' , The Science of the Total Environment , vol. 738 , 140068 . https://doi.org/10.1016/j.scitotenv.2020.140068

http://hdl.handle.net/10138/317403
https://doi.org/10.1016/j.scitotenv.2020.140068

Science of the Total Environment 738 (2020) 140068

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The effects of climate change on Baltic salmon: Framing the problem in collaboration with expert stakeholders

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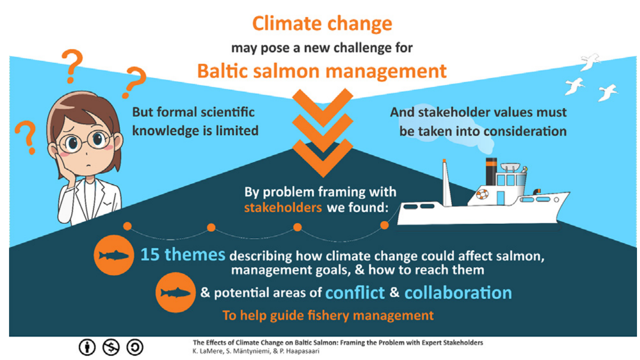
HIGHLIGHTS

- Climate change may pose a challenge for Baltic salmon management.
- We frame the problem using a participatory approach.
- Stakeholders' mental models form the basis of the problem framing.
- 15 key themes holistically describe this problem and its context.
- Understanding areas of conflict and collaboration between stakeholders is crucial.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 13 February 2020
Received in revised form 22 May 2020
Accepted 6 June 2020
Available online 10 June 2020

Editor: Sergi Sabater

Keywords:
Atlantic salmon
Baltic Sea
Climate change
Mental models
Cognitive maps
Participatory modeling
Stakeholder engagement
Expert elicitation
Transdisciplinary research

ABSTRACT

In the Baltic Sea region, salmon are valued for the ecological, economic, and cultural benefits they provide. However, these fish are threatened due to historical overfishing, disease, and reduced access to spawning rivers. Climate change may pose another challenge for salmon management. Therefore, we conducted a problem-framing study to explore the effects climate change may have on salmon and the socio-ecological system they are embedded within. Addressing this emerging issue will require the cooperation of diverse stakeholders and the integration of their knowledge and values in a contentious management context. Therefore, we conducted this problem framing as a participatory process with stakeholders, whose mental models and questionnaire responses form the basis of this study. By framing the climate change problem in this way, we aim to provide a holistic understanding of the problem and incorporate stakeholder perspectives into the management process from an early stage to better address their concerns and establish common ground. We conclude that considering climate change is relevant for Baltic salmon management, although it may not be the most pressing threat facing these fish. Stakeholders disagree about whether climate change will harm or benefit salmon, when it will become a relevant issue in the Baltic context, and whether or not management efforts can mitigate any negative impacts climate change may have on salmon and their fishery. Nevertheless, by synthesizing the stakeholders' influence diagrams, we found 15 themes exemplifying: (1) how climate change may affect salmon, (2) goals for salmon management considering climate change, and (3) strategies for achieving those goals. Further, the stakeholders tended to focus on the riverine environment and the salmon life stages occurring therein, potentially indicating the perceived vulnerability of these life stages to climate change. Interestingly, however, the stakeholders tended to focus on traditional fishery management measures, like catch quotas, to meet their goals for these fish considering climate change. Further, social variables, like "politics," "international cooperation," and "employment"

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https://doi.org/10.1016/j.scitotenv.2020.140068

comprised a large proportion of the stakeholders' diagrams, demonstrating the importance of these factors for salmon management.

1. Introduction

1.1. The Baltic salmon – climate change case study

In the Baltic Sea region in Northern Europe (Fig. 1), Atlantic salmon (*Salmo salar L.*) are popular among recreational fishers, support a commercial fishery (ICES, 2019), and act as a keystone species, providing irreplaceable ecosystem services in both marine and freshwater environments (ICES, 2019; Ignatius and Haapasaari, 2018; Kulmala et al., 2012). These fish are also, in many cases, woven into the cultural heritage of the nations along the Baltic Sea's shore (Ignatius et al., 2019; Ignatius and Haapasaari, 2018; Kulmala et al., 2012; Leeming, 2005; Lönnrot, 2009). Therefore, rapidly declining salmon populations in the 1970s–90s, associated with decades of

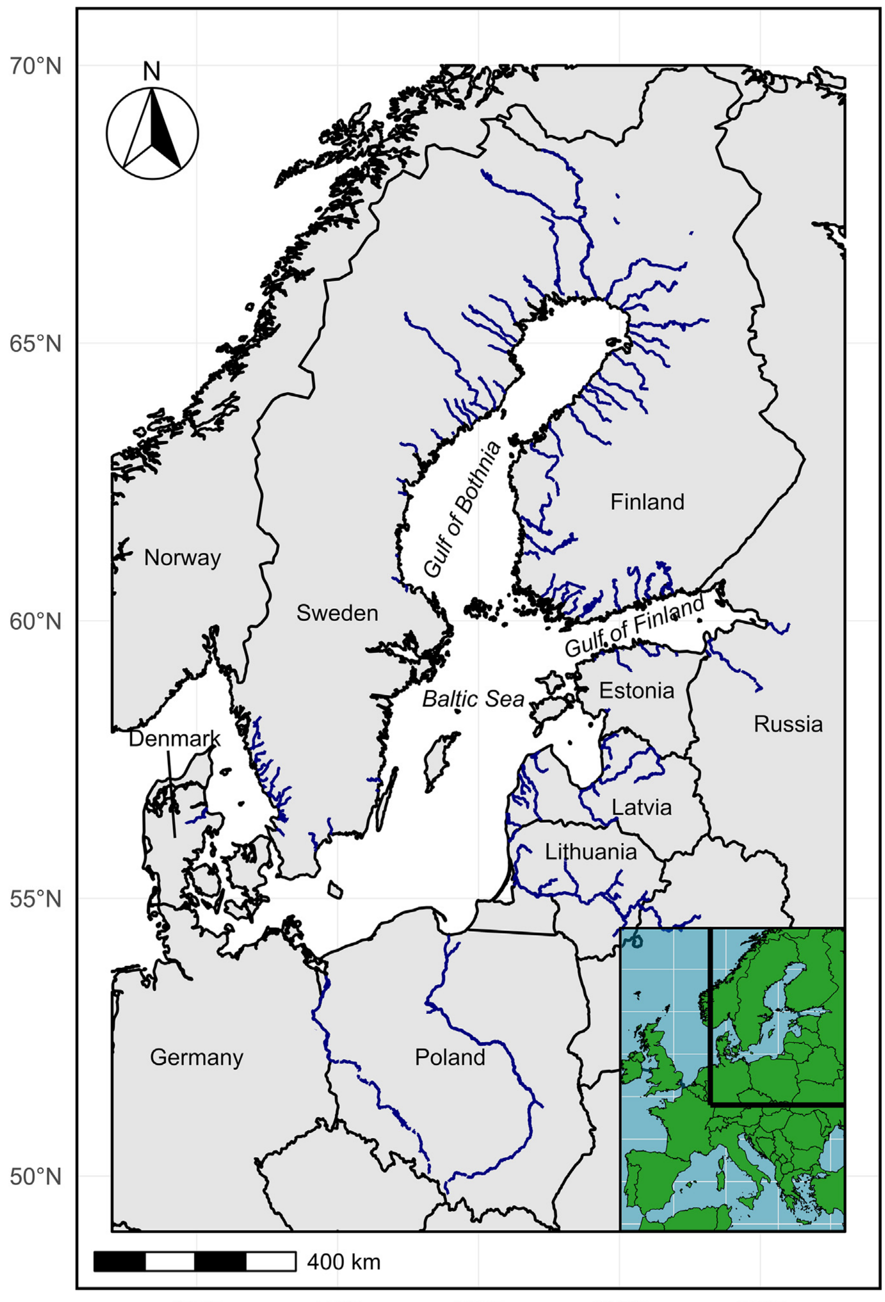

Fig. 1. Salmon rivers in the Baltic Sea Region. Map displaying the Baltic Sea Region and all the salmon rivers therein (dark blue). The inset in the lower right-hand corner depicts the position of the Baltic Sea Region relative to Europe as a whole. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

overfishing, M74 syndrome,[1] and reduced access to spawning rivers (ICES, 2019; Romakkaniemi et al., 2003) were cause for alarm.

Despite the often-contentious nature of the salmon fishery, this concern precipitated the international adoption of the Salmon Action Plan (SAP) in 1997. Under its directive, nine stakeholder nations agreed to aid in the recovery and re-establishment of wild Baltic salmon. Their dedication to this task is often linked to the rebounding salmon populations observed in recent years (Reusch et al., 2018; Romakkaniemi et al., 2003). However, despite these successes, salmon are still considered threatened (HELCOM, 2011; ICES, 2019). Therefore, it is critical that collaborative, multinational management efforts continue to promote the longevity, sustainability, and health of salmon stocks in the Baltic Sea, including prompt action to address emergent threats.

We believe climate change could present a new challenge for Baltic salmon management, as this phenomenon has been shown to compromise the well-being of salmonid species around the world (Eliason et al., 2011), including wild populations of Atlantic salmon[2] outside the Baltic Sea (Almodóvar et al., 2018; Jonsson et al., 2016; Otero et al., 2014).

Like other regions where climatic shifts have affected salmonids, climate change is also occurring in the Baltic region (Bolle et al., 2015; HELCOM, 2013; Räisänen, 2017), where warming is expected to exceed the global average (HELCOM, 2013; Räisänen, 2017). Further, the region's riverine and marine environments, which are both relevant to the survival of anadromous fish, like salmon (ICES, 2019), are expected to change. For example, the scientific community has projected changes in river flow (HELCOM, 2013; Sonnenborg, 2015), further reductions in the extent and duration of sea ice cover, further increases in sea surface temperatures,[3] and shifting sea salinity and acidity (Bolle et al., 2015). Naturally, such changes in the physical environment affect the biological environment as well. As such, studies have acknowledged the potential for climate change to affect, for example, the Baltic Sea food web (Niiranen et al., 2013), the reproductive periods of flora and fauna (Bolle et al., 2015), Baltic fish stocks (Bolle et al., 2015; Koster et al., 2005) and the invasion (Engström-Öst et al., 2015) and proliferation (O'Neill et al., 2017) of harmful cyanobacteria species. New research suggests climate change may also affect the region's social environment, in terms of the mitigation and adaptation challenges that the society will face. For example, by downscaling the global Shared Socioeconomic Pathways (SSPs) for the Baltic Sea, Zandersen et al. (2019) acknowledge the role socio-economic development will play in climate change in the region.[4] Unsurprisingly, given the multitude of changes expected or currently underway in the Baltic Sea Region, we anticipate that salmon will be affected in some way as well.

However, although research about the effects climate change may have on the region's interlinked physical, biological, and social environments is diverse and growing, its effects on salmon and the socio-ecological system they are embedded within[5] are still poorly understood. The research community has produced several articles describing how environmental change affects the Baltic salmon life history (Huusko and Hyvärinen, 2012; Jokikokko et al., 2016; Jutila et al., 2005; Kallio-Nyberg et al., 2004; Snoeijs and Häubner, 2014), which build the foundational theory linking changes in salmon populations to climate change. However, few of these articles consider the issue directly or comprehensively. Further, to the extent that this body of research does consider climate change, it is primarily concerned with changes in the interactions between salmon and their physical and biological environments, leaving out the social environment altogether. At present, to the best of our knowledge, this topic has not been addressed in the literature.

We consider this to be an important area for development because, per the ecosystems approach to fisheries management, we view the physical, biological, and social environments surrounding fisheries issues as interconnected and interdependent (De Young et al., 2008; Ignatius and Haapasaari, 2018). Therefore, to comprehensively understand the problem climate change may pose for the salmon system, it is crucial to acknowledge each of these environments. Hence, the existing research, though vital, only represents a piece of the larger picture. To help develop this knowledge base, this study aims to directly address climate change and assist in producing a more robust, holistic understanding of its effects on the salmon system to advise fishery management.

1.2. The role of participatory methods in the salmon management context

However, while a comprehensive scientific knowledge base is one requirement for addressing large-scale emergent issues, like climate change, a functional fisheries management system is also a necessity. Since the end of the SAP in 2010, salmon management has become increasingly contentious, particularly at the level of the European Union (EU), where stakeholder interests conflict, leading to political stalemate (Ignatius et al., 2019; Ignatius and Haapasaari, 2018; Linke and Jentoft, 2014). These issues seem to be related to two interconnected struggles: (1) the marginalization of different stakeholder groups, their values, and their role in the fishery management process (Ignatius et al., 2019; Ignatius and Haapasaari, 2018; Linke and Jentoft, 2014) and (2) a tendency to ignore the complex socio-ecological context in which salmon management takes place (Linke and Jentoft, 2014).

To meet these challenges, we suggest salmon management must become more inclusive throughout its process, from beginning to end, and consider salmon-related issues from a more holistic perspective. The EU's Common Fisheries Policy (Regulation (EU) No 1380/2013) also acknowledges the importance of involving stakeholders early in the fisheries management process and the value of their diverse knowledge, both of which it considers to be prerequisites for developing sustainable fisheries.

For these reasons, we believe the conversation about the effects of climate change on the salmon system must be inclusive from the outset as well. Therefore, for this study, we chose to use participatory methods, which integrate fishery stakeholders into the scientific process to ensure their views were taken into consideration and that the factors they found relevant were represented. This choice was also beneficial because, in complex, data-poor contexts like this, consulting expert stakeholders is often the best way to build substantive knowledge (Krueger et al., 2012; Kuhnert et al., 2010; Özesmi and Özesmi, 2004; Sutherland, 2006), particularly when action should not be delayed while more formal scientific information is generated (Kangas and Leskinen, 2005; Knol et al., 2010).

1.3. Study goals & aims

As such, the goals of this study were twofold. First, to develop the knowledge base about the effects of climate change on the salmon system in a holistic and socially accountable way to advise fishery management. Second, to provide insight, which could help fishery management efforts meet with success. To meet these goals we conducted a participatory problem framing study, which aimed to (1) improve understanding of the causal relationships between climate change, salmon, and other relevant aspects of the physical, biological, and social environments which comprise the salmon system; (2) identify goals for the management of the salmon system considering the effects of climate

[1] M74 is a diet-related thiamine deficiency syndrome (Keinänen et al., 2017), which causes mortality during the yolk-sac fry developmental stage (Bengtsson et al., 1999).

[2] In this article, the terms "Baltic salmon" or simply, "salmon" refer to Atlantic salmon populations spending the duration of their lives within the Baltic Sea.

[3] The greatest rises in sea surface temperature are expected to occur during summer in the Bothnian Bay and the Bothnian Sea. The majority of the salmon in the Baltic region are born in rivers emptying into these basins (ICES, 2019).

[4] Zandersen et al. (2019) downscaled SSPs to address changes in fish consumption and fisheries management in the region.

[5] From here on we refer to salmon and the socio-ecological system they are embedded within as the "salmon system." Additionally, we refer to the issue climate change may pose for the salmon system as the "salmon-climate change problem."

change; and (3) define potential actions that could be taken to reach those goals. Further, the study aimed to clarify whether or not the climate change issue warrants management action and the sources of conflict and consensus that may develop between stakeholders if it does.

2. Theoretical framework

2.1. Problem framing

To build knowledge about the potential salmon-climate change issue we used an approach known as problem framing. In the context of socio-environmental problem solving, problem framing is a strategy for clearly defining a problem and developing a holistic understanding of it and its context, based on information about, for example, relevant physical, biological, and social factors (Bardwell, 1991; Clark and Stankey, 2006; Haapasaari et al., 2012). By first developing a thorough understanding of a problem in this way, those engaged in a problem-solving effort, i.e. problem solvers,[6] can come to better, more workable solutions. As such, problem framing is an appropriate first step in problem-solving efforts, particularly in complex, uncertain, and even "wicked" contexts (Bardwell, 1991; Haapasaari et al., 2012; Verweij and van Densen, 2010), like the salmon-climate change problem. We perceived problem framing to be an advantageous approach for reaching the goals of this study because the process:

1. *Develops better problem solvers* – During problem framing, problem solvers closely examine and learn about the problem and the surrounding context, developing their conceptualization of the issue. Central to this process is considering the problem from multiple perspectives (Bardwell, 1991; Brugnach et al., 2008), which helps ensure important elements and linkages within the problem system have not been overlooked (Briggs, 2008; Haapasaari et al., 2012) and exposes the personal biases, beliefs, heuristics, and values on which those perspectives are based (Glynn et al., 2017). By framing and re-framing a problem from different perspectives, problem-solvers can relate to the problem in new ways, moving past previously perceived barriers and toward new solutions (Bardwell, 1991). Problem framing also helps direct problem-solvers toward information they lack, by exposing weaknesses in their conceptualizations of the problem (Kaplan and Kaplan, 1982). Further, examining a problem in this way also helps to determine its bounds and scope, which delimits what is and is not possible, what is most important, and what will and will not be addressed. All of which can help break a large, seemingly intractable problem into smaller, more manageable pieces (Briggs, 2008; Kaplan and Kaplan, 1982).

2. *Produces alternative solutions* - Alternative frames, built on alternative perspectives, lead to alternative actions, or solutions (Bardwell, 1991; Brugnach et al., 2008). For example, Tversky and Kahneman, 1981 found that framing an economic problem from the perspective of gains encouraged risk-averse behavior, whereas framing the same problem for the perspective of losses encouraged risk-seeking behavior. Similar examples exist within the natural resource management field (see Brugnach et al. (2008)). As such, the way we define a problem, i.e. the way we perceive it, is critical in determining where the outcomes of problem-solving efforts will ultimately lead (Bardwell, 1991; Pahl-Wostl, 2007). Hence, by problem framing, problem solvers can explore a range of potential solutions that might not have been considered otherwise.

3. *Addresses Conflict* – In collaborative problem-solving contexts, conflict is often unavoidable, as many, often competing, interests must be taken into account (Bardwell, 1991). Indeed, different understandings of a situation are typically the underlying reasons for disputes in environmental management (Haapasaari et al., 2012; Verweij and van Densen, 2010). Therefore, exploring perspectives about an issue and the different concerns, interests, and values they include, helps identify both areas of conflict and consensus that might either hinder or aid management efforts. In this way, problem framing helps determine the correct question(s) to address and ultimately, move toward mutually agreeable solutions as well (Bardwell, 1991). Additionally, understanding different perspectives and the rationale behind them can help bridge gaps in understanding between conflicting groups (Cronin and Weingart, 2019), which may ease conflicts associated with environmental management.

4. *Empowers problem-solvers* - The act of problem-framing itself bolsters a problem solver's sense of competency, as they learn more about the issue, their role in it, and become capable of shifting their perspective (Bardwell, 1991). The sense of self-efficacy these new skills and knowledge bring, in turn, help improve motivation to solve difficult problems (Bardwell, 1991; Biggs and Tang, 2011).

The way a problem is framed subsequently determines the issues and solutions presented to decision-makers (Kueffer et al., 2012; Rittel and Webber, 1973), which reflect not only scientific facts, but also the problem-solvers' values, the tradeoffs they are willing to make, and the risks they are willing to accept (Bardwell, 1991). Therefore, we believe, in the context of natural resource management, including salmon management, problem framing should include all relevant stakeholders' to ensure their knowledge and values are reflected in the decision-making process (Haapasaari et al., 2012; Ignatius et al., 2019). This is particularly true where natural resources are considered common-pool and are managed for the benefit of current and future generations. Further, stakeholders should be included in the problem-framing process, so they too can contribute their perspectives, improve their understanding of themselves, the problem, and others, and address conflict. These outcomes may indeed prove critical for legitimizing and implementing management decisions later on (Fiorino, 1990; Jones et al., 2009), and empowering stakeholders to help tackle complex problems.

2.2. Problem frames as mental models

Central to the problem framing process is understanding, collecting, and building upon the cognitive structures people use to reason, often referred to as mental models, or cognitive maps (Johnson-Laird, 2010; Jones et al., 2011; Nersessian, 2002). Mental models can be thought of as a person's "internal representation of an external reality" (Jones et al., 2011), which encodes their understanding of a system's causal dynamics (Moray, 1998). In problem-solving situations, people automatically access their mental models to interpret and respond to the situation, using it as a reservoir of information from which to draw conclusions (Bardwell, 1991). Studies suggest this kind of informational structure is key for effective problem solving, as problem solvers with more comprehensive and accessible mental models are better able to find effective solutions (Bardwell, 1991).

Naturally, mental models reflect perspective (Johnson-Laird, 2010; Jones et al., 2011). As such, they provide clear insights into the way a person frames and therefore, addresses a particular problem by displaying their hypotheses about a system's causal dynamics (Krueger et al., 2012), what they believe is relevant to the problem, and what they believe is possible within the problem space (Bardwell, 1991). When elicited and aggregated, individual mental models allow for the co-production of systems knowledge (Olazabal et al., 2018)

[6] In this article, we use the term "problem solver" in the same sense as it is used by Bardwell (1991). Although Bardwell (1991) does not define the term explicitly, it is meant to denote a person who is engaged in the process of developing and synthesizing knowledge to identify or create solutions for a given issue. We consider fisheries management and the production of knowledge to support it to be a problem-solving process at its core and therefore, consider those stakeholders who are actively involved in this process to be problem solvers. In this study specifically, the problem solvers include both the authors of this article and the participating expert stakeholders.

and ultimately, a synthesized problem frame. For these reasons, to understand the way stakeholders frame the problem climate change poses for the salmon system, we chose to elicit their mental models about it.

3. Methods

Before describing the methodology used to conduct this problem framing study, we would like to alert the reader to our article LaMere et al. (2020), which describes in greater detail the process we used to elicit and prepare the stakeholders' mental models for analysis, as well as our protocol for administering the questionnaire. While the focus of that previous article was the development of the mental model elicitation methodology, this article focuses on the analysis of the stakeholders' models and the subsequent results.

3.1. Stakeholder selection

For the purpose of problem framing, we studied the mental models of 11 expert stakeholders of the salmon-system from Finland and Sweden. Expert stakeholders from these two nations were targeted because most natural Baltic salmon reproduction occurs in these two nations, they jointly receive approximately 70% of the total commercial catch quota, and the majority of recreational fishing takes place in their waters (ICES, 2019). We only invited experts on the salmon system to participate in this study because we judged this group to have the most extensive knowledge regarding the effects of environmental change on the salmon and their fishery. Those with domain-specific expertise like this have richer pre-existing mental models about the problem (Nersessian, 2002) and should, therefore, be more adept at problem framing about the topic (Bardwell, 1991).

Currently, the distinction between experts, stakeholders, and expert stakeholders is often unclear in the literature (Krueger et al., 2012). For clarification, here we define them as individuals who can be described both as "experts," based on the extent and depth of their experience with the salmon system (Fazey et al., 2006), and "stakeholders," who are considered to be those who will be influenced by the effects climate change may have on the system (Carney et al., 2009; Durham et al., 2014). From here on, the "expert stakeholders" participating in the study will be simply referred to as "stakeholders."

We identified suitable stakeholders for this study via snowball sampling (Matthews and Ross, 2010); first, we reached out to known contacts with suitable expertise and then asked that they pass our request for participation on to other experts. The 11 responding stakeholders we selected demonstrated appropriate contributory and interactional expertise (McBride and Burgman, 2012) regarding the salmon system via their diverse professional backgrounds. These included a transnational management agency, a government ministry, a university, three county management agencies, and five non-government organizations. We assigned each participating stakeholder a letter pseudonym, for example, "stakeholder K," to conceal their identities and respect their privacy. Assuring anonymity is common practice in social scientific research (Bernard, 2018; Marvasti, 2004) because it allows participants to express their true thoughts without fear of retribution or ridicule. This was particularly important for our study given that field of Baltic salmon experts is relatively small and many of our study's participants likely knew one another and because salmon management and climate change may both be perceived as controversial.

3.2. Elicitation: from mental models to influence diagrams

Mental models are internal and therefore, to study them they must be elicited and represented physically. As such, we elicited the stakeholders' mental models as influence diagrams, a type of causal diagram (Haapasaari et al., 2012). These "visualized mental models" clearly articulate the causal relationships between variables within the model by linking them with arrows, which also serve to indicate the direction of the effect (Haapasaari et al., 2012) (see Figs. 3 and 7 for examples). In addition to displaying causal relationships between variables, influence diagrams also acknowledge stakeholders' uncertainty about these relationships, expressed as degrees of belief, which can be elicited either qualitatively (Haapasaari et al., 2012; Varis and Fraboulet-Jussila, 2002; Varis and Lahtela, 2002) or quantitatively as joint probability distributions (Mäntyniemi et al., 2013). Risk assessment models can be easily developed from influence diagrams, when degrees of belief are recorded quantitatively (Haapasaari et al., 2012; Mäntyniemi et al., 2013). However, we chose a qualitative approach for this problem framing study, where uncertainty is represented by the thickness of the arrows drawn between variables (thicker arrows represent more certain relationships) (Haapasaari et al., 2012; Parviainen et al., 2019). Whether quantitative or qualitative, engaging with their mental models by creating influence diagrams, encourages stakeholders to think deeply about the problem, clearly articulate their thoughts, and reflect (Lynam et al., 2007; Marcot et al., 2001; Uusitalo, 2007), which is an essential element of problem framing and helps to improve problem-solving competence as described in Section 2.1.

For this study, the stakeholders' mental models were elicited via the Rich Elicitation Approach (LaMere et al., 2020), which combines direct and indirect mental model elicitation methodologies (Jones et al., 2011; LaMere et al., 2020). The direct portion of the elicitation consisted of an "elicitation session," which is a one-on-one semi-structured interview (Matthews and Ross, 2010) between a stakeholder and a facilitator, during which the stakeholder's mental model is documented as an influence diagram. We used the three following interview prompts during each elicitation (Haapasaari et al., 2012; LaMere et al., 2020):

1. What variables and causal relationships do you think should be considered when determining the impacts of climate change on Baltic salmon and their associated fishery?
2. What goals do you have for salmon and their fishery in the future considering climate change?
3. What management strategies or actions can be undertaken to achieve those goals?

We asked the first question to elicit the stakeholders' mental models of the direct and indirect causal relationships between climate change and the salmon system. Answers to this question were recorded as uncertain variables in the influence diagrams. Collectively, the responses to this question help produce a more comprehensive understanding of the effects climate change may have on the salmon system as perceived by the stakeholders. It also assisted in deepening our understanding of the stakeholders' perspectives of problem, including the elements of the system they are familiar with or find important. The second question elicits the value stakeholders place on salmon and other aspects of the salmon system, which may help to determine potential areas of future conflict or collaboration when managing salmon in the context of climate change. Answers to this question were recorded as goals[7] in the influence diagrams. The third question identified actions[8] that could be taken to reach the aforementioned goals, which broadens the potential pool of solutions for addressing the climate change problem and again, indicates potential areas of conflict and consensus. Answers to this final question were referred to as action variables. Audio was recorded during each elicitation session.

Following direct elicitation, each stakeholder was sent a link to an anonymous online questionnaire, which included questions intended to provide more context for problem framing, determine the utility of the problem framing and mental model elicitation processes, and improve the implementation of those processes. The questionnaire

[7] Referred to utility, loss, or preference of decision nodes in the Bayesian modeling literature (Haapasaari et al., 2012).

[8] Often conceptualized as management options in the Bayesian modeling literature (Haapasaari et al., 2012).

consisted of 18 multiple choice and scoring questions. The majority of these were followed by an open response question asking the stakeholders to elaborate on their answers if desired. Additional information about the implementation of the questionnaire and the questionnaire itself are available in LaMere et al. (2020).

Next, the audio recordings collected during the elicitation sessions were transcribed and the transcriptions were coded. Using the coded transcriptions and notes taken on the transcriptions, each influence diagram was enhanced via indirect elicitation to reduce information loss and oversimplification, which may have occurred during direct elicitation (LaMere et al., 2020). These enhanced versions of the influence diagrams were then sent back to the stakeholders to ensure their thoughts were still represented accurately. Lastly, the terminology used within each influence diagram was standardized (LaMere et al., 2020) to improve their comparability.

3.3. Problem framing analysis & synthesis

After the elicitation process, we conducted two types of analysis, one semi-quantitative and the other, qualitative. Then, we synthesized the results to produce a collective framing based on the individual stakeholders' perspectives.

3.3.1. Semi-quantitative analysis

During the semi-quantitative phase, we deconstructed the influence diagrams and sorted each variable into a hierarchical categorization scheme. We, the co-authors of this article, decided on the categories by observing the data and deliberating about how to categorize them appropriately among ourselves. The variables were sorted into these categories according to our discretion in an effort to decompose the vast amount of information contained in the influence diagrams into more meaningful and easily interpreted themes. For example, using these categories, we were able to identify frequently described categories of variables (i.e. themes) to better understand the areas of the salmon system the stakeholders focused on when considering climate change, and the types of interventions and goals they supported.

Our final categorization scheme included 1st, 2nd, and 3rd order categories, where the first-order categories were the narrowest and 3rd order, the broadest. The 3rd order categories corresponded with the three types of variables included in the influence diagrams: uncertain, goal, and action. We identified five types of uncertain variables, (1) those related to the salmon themselves (salmon-specific)[9]; (2–4) those related to either of the three environments that comprise the salmon system, the physical,[10] biological,[11] and social environments,[12] and (5) those specifically related to the knowledge and uncertainty about the salmon-system that stakeholders wished to represent directly in their influence diagrams.[13] Each of these 3rd order categories was broken down further into more and more specific categories developed according to the variables the influence diagrams contained and our expertise about salmon, the system they inhabit, and the way it is typically managed. An example of our categorization of a specific variable, "volume of high flows" is as follows: 3rd order – "uncertain: physical;" 2nd order – "hydrologic cycle," 1st order – "flow."

We also categorized the variables according to the salmon life stages and environments they were associated with. A variable was placed into a particular "environment category" if it was either 1) a quality of that environment, 2) occurred in that environment, 3) was a quality of something that occurred in that environment; or 4) was specifically intended to impact that environment. For example, the variable "volume of high flows" was classified as related to the riverine environment. The variables that met the requirements for two or more environments were categorized as belonging to both, i.e. a variable related to both the riverine and marine environments was classified as riverine/marine.

Similarly, variables were classified as related to a particular life stage if they: 1) referenced a specific life stage, 2) were a quality or state of a specific life stage, or were 3) a behavior occurring during a specific life stage. Variables related to more than one life stage were labeled as such. For example, some variables pertained to all life stages occurring within the marine environment, therefore these were labeled as "marine phase." Variables, which were not related to a specific environment and/or life stage were given a categorization of "not applicable" (NA) in these areas. For example, life stage was deemed "not applicable" for the "volume of high flows" variable. A full categorized list of all the variables included in the stakeholders' influence diagrams is available as supplementary material associated with this article.

3.3.2. Qualitative analysis & narrative building

For the qualitative analysis portion of this study, we used a conventional content analysis approach (Hsieh and Shannon, 2005). This is an appropriate strategy for concept development or model building (Hsieh and Shannon, 2005), when existing knowledge about the phenomenon in question is limited (Hsieh and Shannon, 2005), as it is for the salmon-climate change problem. The approach's utility in these areas made it a good fit for our problem framing study. Specifically, we used this approach to analyze the transcripts from each stakeholder's elicitation session in conjunction with their influence diagrams, and their responses to the open response questionnaire questions. In practice, this involved identifying and coding concepts within the text and diagrams, then grouping them into larger themes (Hsieh and Shannon, 2005). During this phase, we also produced short narratives summarizing the main concepts included in each stakeholder's frame (see Appendix, Section A.1).

3.3.3. Synthesis

Then, we developed descriptions of each of the primary themes discovered between the stakeholders (see Appendix, Section A.3), using the results of the semi-quantitative analysis to support this process. Those themes which four or more stakeholders contributed to were considered primary. Then, the influence diagrams, transcripts, and narrative summaries were scrutinized again to determine which themes the stakeholders considered to be related and the direction of the causality between them. We documented any causal relationship between primary themes that we found sufficient evidence for within these materials. Lastly, we produced a synthesized influence diagram including the primary themes discovered and the causal relationships we observed between them.

Fig. 2 summarizes the connections between the concepts described in Sections 2.1–3.3.

4. Results

4.1. Influence diagrams

We present the influence diagram one stakeholder produced to represent his mental model of the effect climate change may have on the salmon-system in Fig. 3. However, all 11 of the stakeholders' influence diagrams are available in the supplementary material associated with this article.

[9] Examples of uncertain – salmon-specific variables: "number of smolts" or "egg mortality."
[10] Examples of uncertain – physical variables: "precipitation," "sea temperature," and "flow."
[11] Examples of uncertain – biological variables: "sprat" or "number of seals."
[12] Examples of uncertain – social variables: "national policy" or "commercial fishing effort."
[13] Examples of uncertain – knowledge & uncertainty variables: "uncertainty about food web dynamics" or "data collection."

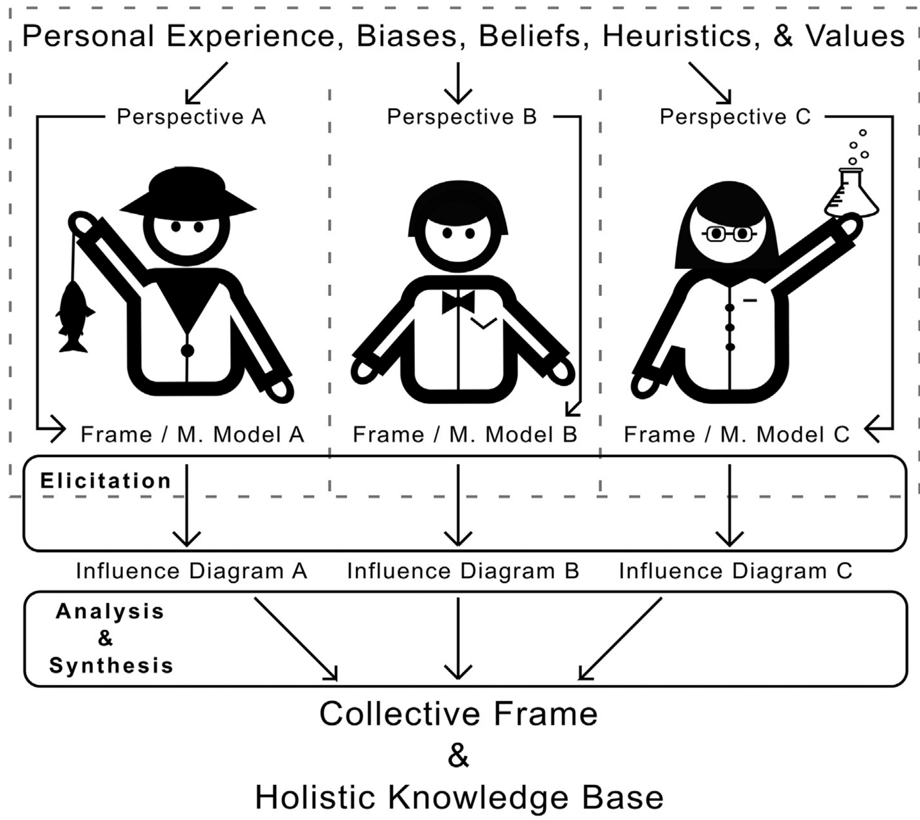

Fig. 2. A synthesis of the study approach. Diagram representing the connection between the concepts described in Sections 2 and 3. The figures represent three hypothetical stakeholders. The arrows can be understood as representing the word "affects" or "influences." Processes occurring internally, in the stakeholders' minds, are within the dashed borders. M. Model stands for "mental model."

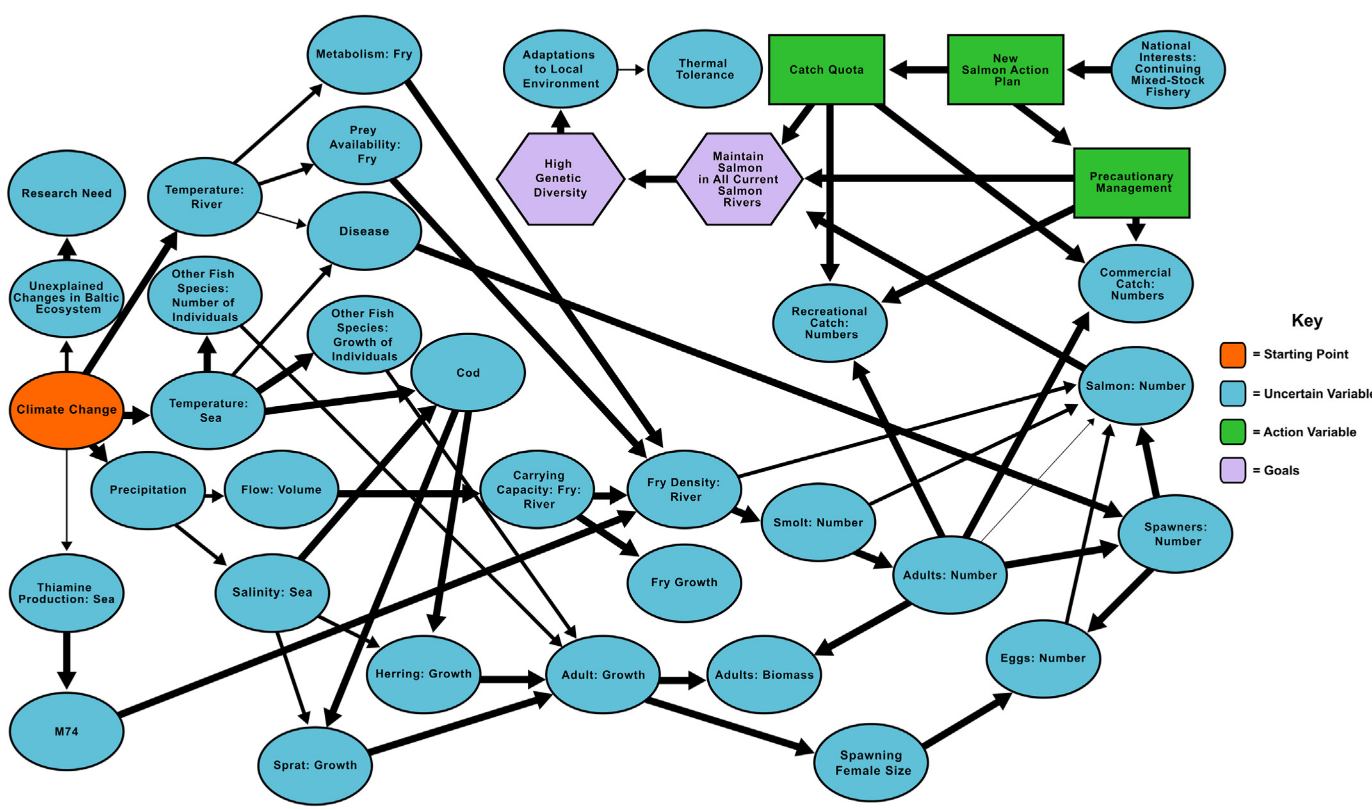

Fig. 3. An example of a stakeholder's influence diagram. Depiction of an influence diagram representing stakeholder F's mental model of the salmon-climate change problem developed using the Rich Elicitation Approach. Each node represents either an uncertain variable, action variable, or goal within the model (see key) and arrows represent causal relationships between variables. Thicker arrows indicate stronger causal relationships.

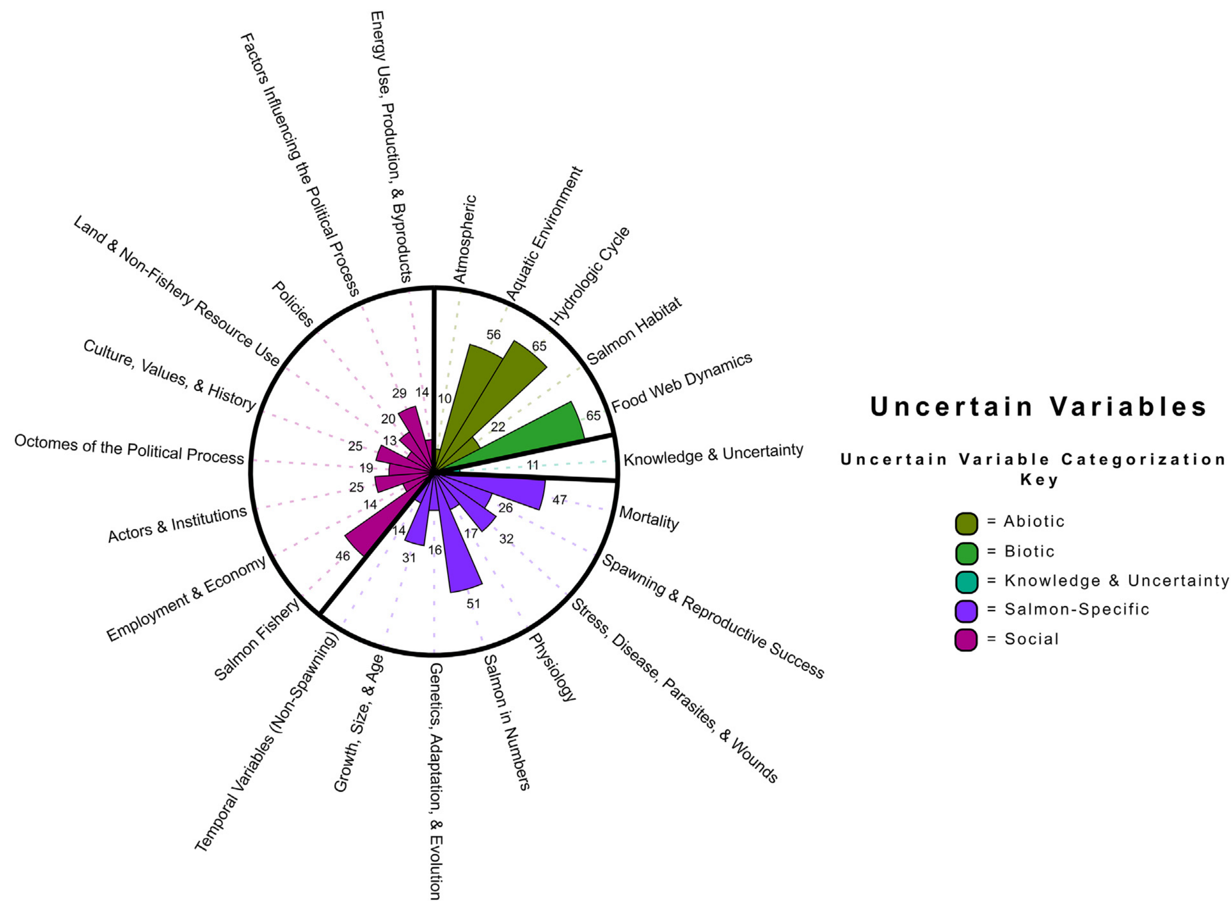

Fig. 4. Categorized uncertain variables. Representation of the 2nd order categories (text) of uncertain variables grouped by the 3rd order categories (color, see key) they fall within. Each 2nd order category is labeled with the number of individual variables it contains. Only the 2nd order categories including ≥10 variables are included in this diagram. These results were produced during the semi-quantitative phase of data analysis.

4.2. Qualitative results

The narratives developed to summarize each stakeholder's influence diagram and elicitation session notes are available in the Appendix, Section A.1.

4.3. Semi-quantitative results

Combined, the 11 stakeholder influence diagrams contained 718 uncertain variables. From Fig. 4 we can see the prominence of different ideas or themes within the stakeholders' influence diagrams. For example, food web dynamics and the hydrologic cycle are represented strongly, with each of the two categories containing 65 variables from across the 11 influence diagrams. Bear in mind, these are not numbers of "unique" variables. Meaning that in many cases the same variable may have been reiterated by several stakeholders. Unsurprisingly, the greatest number of uncertain variables are included in the salmon-specific variables category. However, the social variables category contains the second most and the highest number of 2nd order categorizations, indicating greater diversity in the stakeholders' conceptualization of this portion of the salmon system.

Table 1 depicts the uncertain variables most frequently used across the 11 influence diagrams. All the uncertain variables included in five

Table 1
The uncertain variables most frequently included in stakeholders' influence diagrams.

Uncertain variable	1st order categorization	2nd order categorization	3rd order categorization	Number of stakeholders
Temperature: river	Water temperature	Qualities of aquatic environment & influencing processes	Uncertain: physical	11
Temperature: sea	Water temperature	Qualities of aquatic environment & influencing processes	Uncertain: physical	10
Smolt: number	Number	Salmon in numbers	Uncertain: salmon-specific	6
Spawners: number	Number	Salmon in numbers	Uncertain: salmon-specific	6
Spawning migration: timing	Spatial & temporal spawning variables	Spawning & reproductive success	Uncertain: salmon-specific	5
Adults: number	Number	Salmon in numbers	Uncertain: salmon-specific	5
Egg mortality	Natural mortality	Mortality	Uncertain: salmon-specific	5
Eggs: number	Number	Salmon in numbers	Uncertain: salmon-specific	5
Hydropower	Energy production	Energy use, energy production, & byproducts	Uncertain: social	5
Ice cover: river	Ice	Hydrologic cycle	Uncertain: physical	5
Parr: number	Number	Salmon in numbers	Uncertain: salmon-specific	5
Spawning female size	Size	Growth, size & age	Uncertain: salmon-specific	5
Temperature: air	Air temperature	Atmospheric	Uncertain: physical	5

or more diagrams are included in the table. River and sea temperature occurred most frequently and the number of salmon at different life stages was frequently mentioned as well.

The uncertain variables most frequently (≥5 times) included in stakeholders' influence diagrams and their 1st, 2nd, and 3rd order categorization. The "Number of Stakeholders" column indicates how many stakeholders included the variable in their influence diagrams. These results were produced during the semi-quantitative phase of data analysis.

Altogether, the 11 influence diagrams included 48 goals. These were divided into three 2nd order categories; 1) biological, which included goals related to the salmon and the ecological community, like "protect biodiversity" and "climate change adaptation;" 2) knowledge, which contained goals related to improving the state of knowledge, for example, "improved reliability of catch statistics" and 3) socioeconomic, which included goals like "societal wellbeing" and "achieve fishery sustainability." Fig. A.1 depicts all 1st order goal categories grouped by the 2nd order categories described above. The figure shows that the influence diagrams contained a nearly equal number of biological and socioeconomic goals, 22 and 23, respectively. The biological goals were more uniform, however, again demonstrating higher diversity among the stakeholders regarding their mental models of the social portion of the salmon system.

The influence diagrams also included 122 actions that could be taken to reach the aforementioned goals. These actions were divided into nine 2nd order categories (Fig. A.2). The largest of these categories was action related to salmon fishery management and regulations, with catch quotas and bag limits being the tools the stakeholders most frequently described to achieve their goals for the salmon system in the context of climate change.

As depicted in Fig. 5, the most frequently described environment was the riverine environment, followed by the marine environment. Some variables like those related to fishing generally were categorized as riverine/marine, as fishing for salmon occurs in both these environments, and in the absence of further information, these could not be reliably classified as belonging to one environment or the other. The spawning phase was the most often mentioned salmon life stage and in total, the riverine phases of the salmon lifecycle were more frequently mentioned than the marine phases (Fig. A.3).

The data set containing the hierarchical, environment, and life stage categorizations for each variable from all 11 influence diagrams is available as supplementary data associated with this article.

4.4. Questionnaire results

The majority of stakeholders acknowledged that specific stocks were important to them and identified eight salmon groups of interest (Table 2). These included both specific stocks, those originating from a particular river, and broader salmon groups potentially comprised of multiple stocks. Like, for example, "weak stocks" or salmon in the "Gulf of Bothnia" generally.

The stakeholders also rated their satisfaction with the current management of Baltic salmon generally and of the specific salmon groups they chose, and their satisfaction with the current status of Baltic salmon generally. Typically, stakeholders were neutral or positive about the management of the Finnish and Swedish stocks they named, except Simojoki, whose management was perceived as satisfactory by some and not by others. Those interested in weak Baltic salmon stocks or the Gulf of Bothnia stocks more generally, were dissatisfied with their management. Their feelings about the management of Baltic stocks as a whole, were either neutral or dissatisfied. The stakeholders' responses about their satisfaction with the current status of Baltic salmon were mixed, ranging from dissatisfied to satisfied.

Several stakeholders also chose to submit short written responses about their satisfaction with the current management and status of Baltic salmon stocks. Typically, they focused on their reasons for dissatisfaction, although a few did mention that some stocks have been improving, indicating satisfactory management. Their reasons for dissatisfaction included the following: poaching and misreporting by countries other than Finland and Sweden, continued mix-stock fishing in the Baltic proper, a lack of effective river restoration, a lack of positive development for smaller stocks compared to larger ones, a lack of a common salmon management plan between Finland and Sweden, the need for more reliable catch statistics, a lack of a long-term

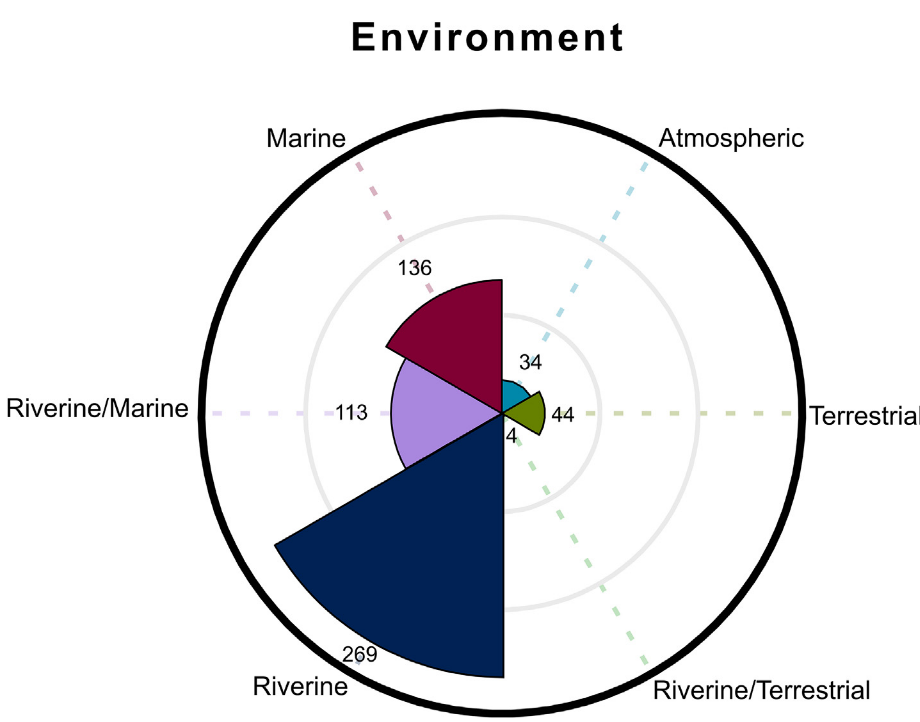

Fig. 5. Frequency of different environments occurring within stakeholders' influence diagrams. Those variables related to two environments are designated with a "/," i.e. any variables related to both the river and sea are categorized as "Riverine/Marine." These results were produced during the semi-quantitative phase of data analysis.

management plan (SAP), a short, intensive fishing seasons requiring large amounts of salmon to be sold at once for a low price, the need for more fishing gear regulations in some areas, and a lack of stock-specific management plans.

In answers to the open response questions, most stakeholders acknowledged that the status of salmon in the Baltic is currently good or at least improving, particularly in the cases of the Tornionjoki and Simojoki stocks. However, despite this positive outlook, most acknowledged that many stocks are still in poor condition and that there is plenty of work to be done to improve the status of Baltic salmon overall. Most commonly, stakeholders described riverine issues, in particular, the need for habitat restoration and the removal of hydroelectric dams. Fishing pressure was also described as a threat to Baltic salmon, specifically mixed-stock fishing, which occurs when fishing in the Baltic proper where adult salmon from multiple stocks mix as they feed. There was some indication that fishery management was working well in Finland and Sweden, but perhaps not in other countries. Disease and lack of a SAP were also described as threats to salmon.

The stakeholders were also asked a suite of questions regarding salmon and climate change (Table 2). Most agreed it is important to consider the effects climate change will have on natural resources when making management decisions and all eleven reported they had previously thought about the effects climate change could have on salmon. Most believed it is likely that climate change will affect salmon in the foreseeable future and that these effects will be significant. However, the stakeholders' views about whether these effects would be negative or positive were mixed, although there were more negative than positive responses. The stakeholders' conceptualizations of the foreseeable future were also likely diverse because their beliefs about when the effects of climate change on salmon would become evident were mixed, spanning from "they already are" to "in 20–50" years. When asked whether or not management would be able to mitigate negative effects of climate change, the stakeholders' responses were fairly evenly distributed; with some reporting that management can mitigate these effects and others reporting that it cannot. Despite this, most stakeholders agreed that if we had a better understanding of how climate change may affect salmon, management could make decisions to better prepare the fishery for the future.

Table 2. The stakeholders' responses to questionnaire questions regarding (A) their satisfaction with the status and management of Baltic salmon, and (B) the importance and relevance of climate change to salmon management. In Section A, the stakeholders were asked to write in the specific stocks that were important to them (specified stocks) and provide a rating of their satisfaction with the management of those stocks specifically and Baltic salmon generally. Questionnaire questions and the raking scale used for each question are italicized. Response options are in bold. Each X represents one stakeholder's response. Xs in the NR column indicate stakeholders who chose not to respond to the question.

When asked to explain their answers regarding whether or not will climate change be positive or negative for Baltic salmon, some stakeholders suggested that salmon production could increase, particularly in the northern Baltic, perhaps as the result of a longer growing season and a faster lifecycle. However, others mentioned that climate change

Table 2
The stakeholders' responses to questionnaire questions regarding (A) their satisfaction with the status and management of Baltic salmon, and (B) the importance and relevance of climate change to salmon management. In Section A, the stakeholders were asked to write in the specific stocks that were important to them (specified stocks) and provide a rating of their satisfaction with the management of those stocks specifically and Baltic salmon generally. Questionnaire questions and the raking scale used for each question are italicized. Response options are in bold. Each X represents one stakeholder's response. Xs in the NR column indicate stakeholders who chose not to respond to the question.

A. Satisfaction with Salmon Management in General & for Specific Stocks										
Questions:	NR	Yes	No							
Are specific Baltic salmon stock important to you?		XXXXXXXXX	XX							
How satisfied are you with the current management of the Baltic salmon stocks you specified & Baltic salmon in general? (1 = Dissatisfied, 5 = Satisfied)										
Specified Stocks:	**NR**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
Tornionjoki/Torneå						XX		XX		X
Simojoki				XX		X		X		
Kalix						X		X		
Råne								X		
Mörrumsån						X				
Gulf of Finland: Weak Stocks		X								
Weak Stocks		X		X						
Gulf Of Bothnia				X						
Baltic Stocks in General				XXXX		XXXXXXX				
How satisfied are you with the current status of Baltic salmon stocks? (1 = Dissatisfied, 5 = Satisfied)			X	XXXX		X	XX	XXX		
B. The Importance of Climate Change for Salmon Management										
Questions:	**NR**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
How important is it to consider the effect climate change may have on natural resources in making management decisions? (1 = Unimportant 5 = Important)				X		XX		XXX		XXXXX
How likely is climate change to have an effect on salmon in the foreseeable future? (1 = Unlikely 5 = Likely)				X		X		XXX		XXXXXX
How significant will these effects be? (1 = Insignificant 5 = Significant)	X			X		XX		XXXXX		XX
Overall, will climate change be positive or negative for Baltic salmon? (1 = Negative, 5 =Positive)	XX	XXX	X			XXX		XX		
If the effects climate change will have on Baltic salmon are negative, how much can management mitigate these effects? (1= Not at all, 5 = A lot)		XX		X	X	X	X	XXX		X
If we had a better understanding of how climate change may influence salmon, could we make management decisions to help prepare the fishery for the future? (1 = No, definitely not, 5 = Yes, definitely)				X		X		XXXXX		XXXX
	NR	**Yes**	**No**							
Have you thought about the effects of climate change on salmon before?		XXXXXXXXXXX								
	NR	**They already are**	**In <5 years**	**In 5–10 years**	**In 10–20 years**	**In 20–50 years**				
When will (the effects of climate change on salmon) become evident?		XXXX	X	X	XXXX	X				

may also worsen conditions for salmon in the southern Baltic. Stakeholders described potential changes in water temperature, runoff, river flow, drought, the Baltic food web, feeding areas, disease, and temporal shifts in lifecycle phases (spawning, migrating, and hatching). A few stakeholders found it difficult or even impossible to speculate about the effects climate change could have on Baltic salmon.

4.5. Primary themes from the problem-framing process

Fifteen primary themes became evident from the stakeholders' frames. These themes are each described in the appendix, Section A.3, and are depicted in Fig. 6 below. Fig. 6 shows which theme each stakeholder discussed and the total number of stakeholders that discussed each theme. In the figure, each theme is represented by an abbreviated name (see Appendix, Section A.3).

4.6. Synthesis

The influence diagram in Fig. 7 represents a synthesis of the 15 primary and the causal relationships between them as described by the stakeholders. In this synthesized view, climate change could affect food web dynamics, create phenological mismatches between salmon and their prey, accelerate the salmon lifecycle, cause heat stress in the riverine environment, change disease prevalence, alter river flow, and cause changes in fishing, each of which affects salmon.

In addition to the effects of climate change, during their elicitation session and in their questionnaire responses the stakeholders also described other drivers of ecological change they believe will affect the future status of Baltic salmon. The greatest proportion of these was related to the degradation of the riverine environment caused by anthropogenic factors, like forestry practices, peat mining, water usage, and hydropower. The "human impacts on the riverine environment" node in Fig. 7 represents this idea.

Three themes are depicted as goals in Fig. 7. The first of these, increase salmon populations, is a reflection of all 11 stakeholders' unsurprising desire to see Baltic salmon populations continuing to grow and thrive into the future. However, the stakeholders did describe different motivations for suggesting this goal including to support predator populations, for the intrinsic value of salmon themselves, for the wellbeing of future generations of people, and to support fisheries. As such, this goal is tightly coupled with the second, to ensure the economic security and wellbeing of fishers and their communities. The majority of stakeholders of all different backgrounds, described the importance of maintaining strong fish stocks, which generate revenue via the commercial fishery and increasingly, the recreational fishery as well. In particular, the stakeholders described the importance of this income source in northern Baltic towns, where employment opportunities are often limited. However, most stakeholders acknowledged that salmon must be protected from overfishing nevertheless, which is still a concern despite the increasing size of several stocks. The stakeholders considered the protection of genetic diversity, the last of the goal-related themes, to be crucial, as it provides the best chances for adaptation to ecological change, including climate change. Central to this goal was maintaining and strengthening weak and vulnerable stocks, which they frequently

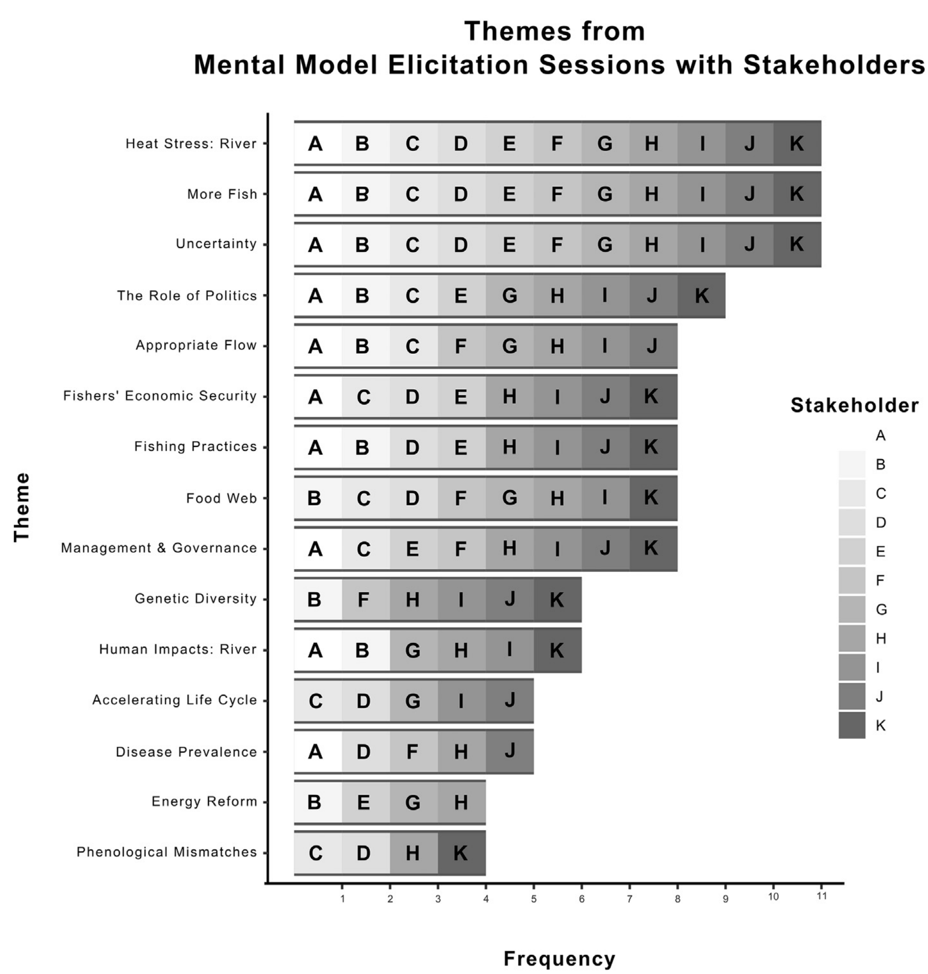

Fig. 6. The number of stakeholders discussing each of the 15 primary themes detected across the 11 influence diagrams. Themes considered to be 'primary' were described by ≥4 stakeholders. The stakeholders contributing to the theme are represented by their letter pseudonyms (key). These results were obtained during the synthesis phase of our analysis.

described as those originating in the southern Baltic region. According to several stakeholders, those stocks are both currently in worse condition than the northern stocks and are more likely to be negatively affected by climate change-driven environmental changes, like reduced flow and rising river temperatures in the near term.

Throughout the stakeholders' elicitation sessions we found three overarching strategies for reaching the goals described above. The first of these was continuing to improve salmon management and governance. Many of the stakeholders were concerned about, for example, the threat of overfishing, fishing opportunity inequalities between nations, and overly lenient regulations on the growing recreational fishery. As such, the stakeholders described a variety of measures, primarily via adjusting quotas and catch reporting requirements, which should be implemented. Additionally, to protect and strengthen individual stocks according to their unique circumstances, several stakeholders suggested stock-specific management plans and banning mixed-stock fishing, to reduce fishing pressure on weak salmon stocks. Instead, they argued, salmon should be fished close to their natal rivers, as is the current practice in Finland and Sweden, to ensure only those stocks strong enough to support a harvest are fished. A few stakeholders also urged precautionary management in the face of the uncertainty that climate change brings and others suggested adaptive management strategies. For example, ending the fishing season early if environmental conditions like water temperature become too taxing for salmon to support fishing as well. Unlike fishery management reforms, most stakeholders did not view political action, the second action-related theme, as within their direct control, although most described the importance of the political system and how it ultimately affects fisheries management, energy, and land-use decisions. However, some stakeholders did suggest their role in advocates. In some cases, stakeholders described the governance process, how to influence it, and the importance of doing so in detail. Notably, the stakeholders described the importance of policy in reforming energy use and energy production strategies, the third action-related theme. According to some stakeholders, changing energy use and production practices is the only route society truly has to influence the progression of climate change. Further, changes in policy also affect decisions about whether to build or remove hydropower plants.

Lastly, all the stakeholders expressed their uncertainty about how climate change will affect the salmon system, with some even adding uncertainty as a variable in their influence diagrams. Therefore, we

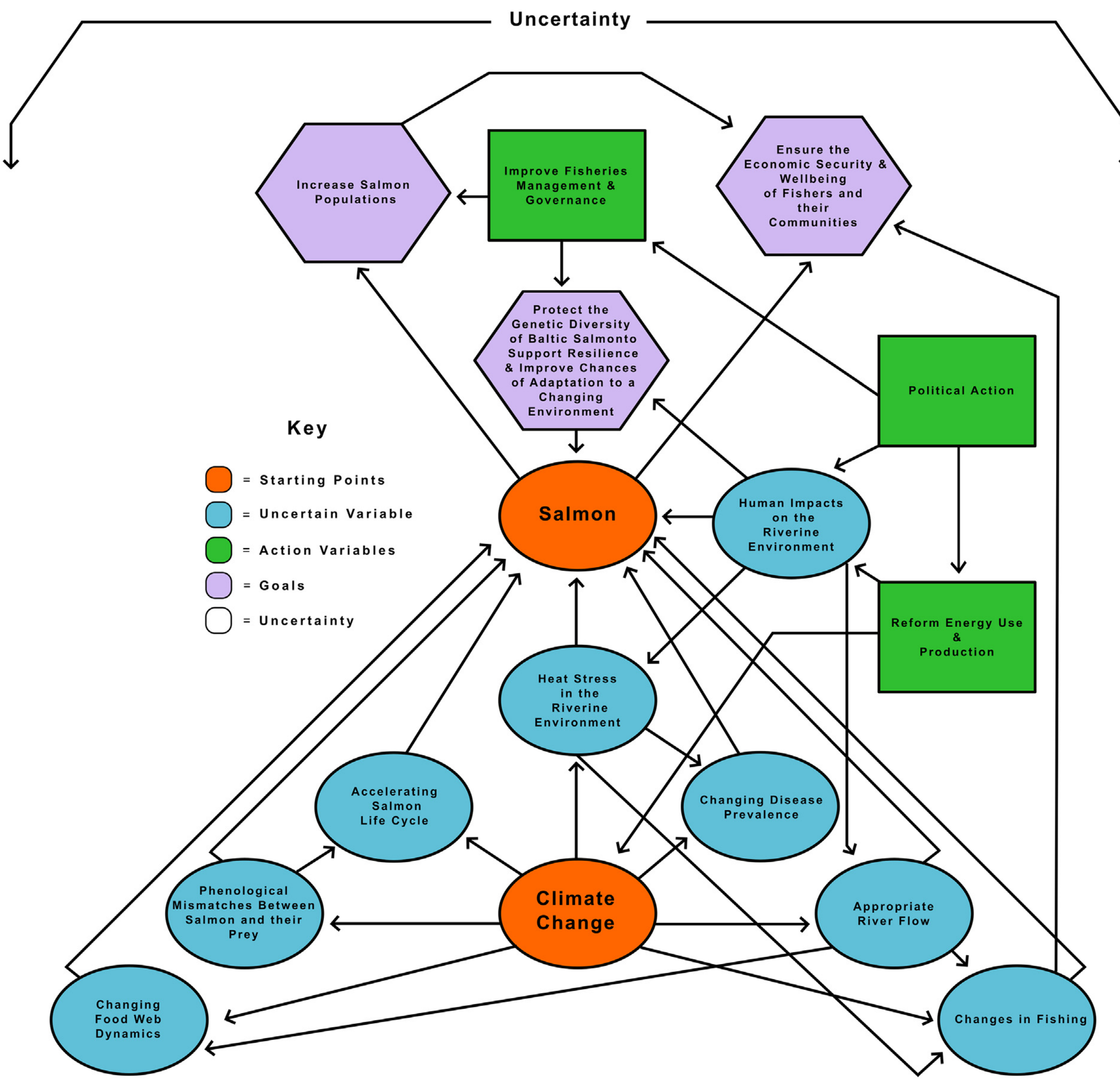

Fig. 7. Synthesis influence diagram. The diagram describes the causal relationships between the 15 primary themes found within the 11 individual stakeholder influence diagrams. See Section 3.2 for information about interpreting influence diagrams. The results were obtained during the synthesis phases of our analysis.

placed uncertainty outside the synthesized influence diagram to represent the uncertainty the stakeholders felt about how climate change could affect the salmon system.

5. Discussion

5.1. Synthesis discussion

Most of the climate change-induced effects listed as variables in Fig. 7 (the 15 themes) have been previously described as potential threats to either Baltic salmon specifically (HELCOM, 2011), or Atlantic salmon more generally (ICES, 2017; Jonsson and Jonsson, 2009). For example, in their 2017 report, ICES discusses many of the same concepts addressed by the stakeholders, including the impacts of climate change on disease prevalence and age at maturity (accelerating life cycle), among others. Multiple reports also describe the importance of maintaining the genetic diversity of salmon (ICES, 2017, 2019; Reusch et al., 2018). Further, Lassalle and Rochard, 2009 found that under conditions predicted for 21st-century climate change, salmon populations are likely to diminish to some extent in the southern Baltic, a concern held by the stakeholders as well. Researchers have also already extensively studied and documented the impacts of anthropogenic activities in the riverine environment and catchment areas on salmon (Elliott et al., 1998; Rivinoja et al., 2001; Romakkaniemi et al., 2003; Young et al., 2011).

As such, the existing literature supports the stakeholders' biological and environmental thinking on a broad level. Indeed, existing literature may have informed the stakeholders' mental models about the effects of climate change on the salmon system. However, even if this is true, the stakeholders specifically applied this information to the Baltic context, where literature about the effects of climate change on salmon is still limited. The stakeholders' influence diagrams also provided a more detailed account of the causal relationships between these ideas than documented previously. The causal chains they created in their influence diagrams can be thought of as alternative hypotheses about how different variables within the salmon system interact. The primary themes within these causal chains are represented within the synthesized influence diagram, Fig. 7. For example, Fig. 7 suggests that, according to the stakeholders, climate change could cause changes in fishing practices. The interested reader can view the influence diagrams and narrative summaries (included in the supplementary material and appendix, respectively) of those stakeholders who discussed this topic (see Fig. 6) for more insight into their hypotheses about the relationship between these variables. This study leaves us with a great number of new questions and hypotheses about the mechanisms by which variables affect one another within the context of the salmon-climate change problem, but this is progress nevertheless, as it presents a foundation to build upon.

The stakeholders' knowledge also provides a more holistic view of the climate change issue in the Baltic context than has been produced previously, as it includes not only the physical and biological environments but their connections with the social environment as well. Although Zandersen et al. (2019) have laid the foundations for investigating the interconnected implications of climate change and societal development of fisheries in the Baltic Sea area, we believe the stakeholders' knowledge could help define this issue more precisely. For example, the stakeholders describe specific changes in the effectiveness of certain gear types and fisher behavior that may occur as climate change continues (see Section A.3.10). As such, this may be an interesting line of inquiry for future studies.

Along these lines, we would also like to draw the reader's attention to the importance and prevalence of social variables within the stakeholders' conceptualizations of the climate change problem. As depicted in Fig. 4, the 3rd order categorization, uncertain: social variables, was the second-largest, following the category for uncertain: salmon-specific variables. The social variables category also contained the highest number of 2nd order categories, indicating the greatest diversity in the variables described. Put another way, the stakeholders had the most divergent perspectives about the social system relative to the other variable categories. Although each influence diagram contained different proportions of each 3rd order category, all contained at least some description of the social system, indicating its integralness to the stakeholders' understandings of the climate change-salmon system issue. This finding reiterates the central role of the social system in fisheries management (De Young et al., 2008), including Baltic salmon management (Linke and Jentoft, 2014), which must not be forgotten when addressing the climate change issue.

The greatest proportion of the environment-related variables included in the influence diagrams concerned the riverine environment and the greatest proportion of the life phase-related variables concerned the spawning stage, which occurs therein. The spawning phase, in combination with the other life stages occurring in the river, comprises the majority of the life phase-related variables. This information may indicate the stakeholders found the riverine environment and riverine phases of the salmon life cycle to be most relevant in the context of climate change or potentially, the most vulnerable to its effects. Alternatively, it could also reflect the greater complexity of the portions of the salmon life cycle occurring within the riverine environment or the state of the stakeholders' knowledge. As such, we encourage future studies to address this topic directly, which may be useful for prioritizing management efforts and allocating resources.

The importance of promoting Baltic salmon's resilience dominates the management actions proposed by the stakeholders. It appears they, as a group, believed the best way to address the effects climate change may have on the salmon system is to reduce other stressors as much as possible, perhaps as determined on a stock-by-stock basis. Therefore, it seems reasonable that the most frequently described action variables were catch quotas and bag limits (Fig. A.2), as fishing has historically had a strong influence on the size of the Baltic salmon population (Romakkaniemi et al., 2003). However, we find it interesting that although the greatest number of variables in both the individual and synthesized influence diagrams represented the riverine environment and described climate change-induced stressors therein (Fig. 5), few action variables targeted rivers. Of course, fishing occurs within rivers as well as the sea. Nevertheless, comparatively few actions addressed the climate change-related stressors salmon may face in the riverine environment. The action variables most directly linked to the riverine environment are included in the “salmon habitat management” and “land use and catchment area” categories in Fig. A.2. We believe this omission may reflect past reliance on catch regulations to manage the fishery, however, climate change may necessitate the expanded use of a broader arsenal of management tools, like riverine habitat protection and restoration, including collaborative efforts with, for example, the forestry, agricultural, and hydropower industries. Further, options for mitigating stressors primarily experience in the riverine environment, like high water temperatures, have been suggested, including increasing tree cover in riparian zones (Blann et al., 2002) and protecting groundwater sources (Carlson et al., 2017), both of which may serve to keep water temperatures low.

5.2. Conflicts & collaboration

In addition to producing a more holistic picture of the effects climate change may have on the salmon system, this study also provided insight into the areas of conflict and consensus that incorporating climate change into the salmon management discussion might encourage. Although there may be disagreement about the specifics, synthesis influence diagrams like ours (Fig. 7), could be used to illustrate broad areas of consensus within problem framing groups to help to drive discussion forward productively. However, as the previous sections describe our participants' synthesized frame and hence the concepts they tend to agree on, we will use the remainder of this section to describe the potential areas of conflict we found between them.

First, although most stakeholders believed climate change will affect salmon significantly, opinions about whether those effects will be negative or positive were more mixed (Table 2). Further, while most believed climate change will affect salmon in the foreseeable future, they disagreed about when that foreseeable future will arrive. For example, some stakeholders believed the effects of climate change on salmon are already evident, while others felt they would become evident later, or even much later (Table 2). As such, whether or not climate change is indeed a threat to Baltic salmon may be in question. If it is a threat, whether or not it is currently relevant might also prove controversial.

Along these lines, during their problem framing sessions, some stakeholders alluded that while climate change is a problem, other issues like overfishing and anthropogenic habitat degradation are more pressing and therefore, more resources and effort should be allocated to correcting them. The stakeholders' attention to anthropogenic impacts on the riverine environment and improving regulations to prevent overfishing in their influence diagrams also emphasize that at least some of them may view these stressors as more relevant than climate change, at least for the time being. Räisänen (2017) came to similar conclusions, stating that in the future, the effects of climate change may be overshadowed by other anthropogenic changes in the Baltic region. On the other hand, the stakeholders' inattention to managing the effects of climate change directly could also have less to do with its low position on their lists of fishery management priorities, and more to do with feelings of helplessness. Perhaps, stakeholders are more apt to focus on stressors they believe they have more control over, like the overfishing. The mixed responses we received about the efficacy of fishery management to mitigate the effects of climate change could indicate the perceived futility some stakeholders feel about managing the effects of climate change on fisheries. However, the results of our study do not decisively conclude how the stakeholders would rank other anthropogenic impacts in comparison with climate change as priorities for salmon management, nor do they define their rationale behind these rankings. This matter should be investigated further by future studies to help fishery management prioritize its efforts according to the values and expertise of fishery stakeholders. Despite the pertinence of other threats to the salmon system, many stakeholders did believe that climate change would have negative impacts on salmon and that a better understanding of its effects could help prepare fishery management for the future, as described previously (Table 2). At the very least, climate change represents an additional environmental stressor that may compound the issues associated with other anthropogenic stressors and is likely to increase in importance into the future (Räisänen, 2017). Therefore, the issue warrants investigation now.

Another potential conflict we envision is about the management of weak salmon stocks in the Southern Baltic, which some stakeholders consider to be the key to safeguarding genetic diversity. While several stakeholders reported they were neutral or satisfied with the management of Finnish and Swedish stocks, two reported they were dissatisfied with the management of weak stocks and all were either neutral or dissatisfied with the management of Baltic salmon in general. Additionally, during their elicitation sessions, several stakeholders described the importance of protecting and improving the management of the southern stocks. This indicates that some Finnish and Swedish stakeholders may not be satisfied with the southern Baltic nations' salmon management strategies or perceive that changes will become necessary as climate change continues. If the nations surrounding the Baltic Sea decide to discuss the climate change issue collectively, under, for example, the directive of a new SAP, this issue should be considered thoroughly ahead of time, and statements should be structured to promote constructive problem solving rather than unproductive criticism. Further, if ending mixed stock fishing were suggested as a strategy to avoid overfishing weak stocks, thoughtful, perhaps creative concessions for those southern nations who would then be excluded from the fishery should be proposed.

Continuing with international relations, several stakeholders described strong relations between Finland and Sweden regarding salmon management. They viewed the proliferation of the Tornionjoki/Torneå salmon stock as a joint management success and seemed pleased that both nations had decided to stop longline fishing targeting mixed salmon stocks feeding in Baltic Main Basin. However, some stakeholders did call for improved cooperation between Finland and Sweden and even a joint salmon management plan. In particular, one stakeholder discussed the importance of changing regulations to equalize competition between Finnish and Swedish commercial fishers (see Appendix, Section A.1.1). Although this concern is not directly related to climate change, strong cooperative relationships between nations can only be beneficial for addressing complex problems like environmental change.

Additional conflicts may arise surrounding increased competition between salmon and humans for riverine resources. For example, climate change may increase the demand for renewable energy, including hydropower. Indeed hydropeaking, the practice of releasing pulses of water to meet electricity demand, has increased in Nordic rivers in recent years, indicating rising consumption of hydroelectric power (Ashraf et al., 2018). Hydroelectric dams reduce salmon's access to spawning grounds, even when fishways are available (Rivinoja et al., 2001) and also affect the quality and quantity of both downstream and upstream habitat. Specifically, because hydropeaking influences fish behavior (Scruton et al., 2003; Young et al., 2011), mortality (Saltveit et al., 2001; Young et al., 2011), and spawning (Haas et al., 2016; Vollset et al., 2016; Young et al., 2011). To reduce the conflicting interests between increasing hydropower demand and salmon habitat, we suggest the timing and magnitude of hydropeaking-related water discharge fluctuations should be adjusted to be as sensitive as possible to salmon requirements (Harnish et al., 2014). Stakeholder G suggested an alternative strategy to manage the trade-off between salmon and hydropower. He proposed the creation of a few high-efficiency hydroelectric dams on large Swedish rivers and removing less efficient, older dams from smaller rivers. Then, rehabilitating the small rivers to provide suitable habitat for salmon (see Appendix, Section A.1.7). In addition to hydropower, increasing municipal and industrial demand for water could exacerbate increasingly prevalent drought conditions in some areas.

Lastly, as described previously, the stakeholders recognized the importance of balancing the health of salmon stocks with the economic security and wellbeing of fishers and their communities. Measures to protect salmon stocks from overexploitation, like reduced quotas and ending the mixed stock fishery, could reduce profit margins for fishers or exclude them from the fishery altogether, creating conflict. Climate change could exacerbate this pre-existing problem, either by diminishing salmon stocks or by inciting proactive management to reduce salmon mortality or conserve weak populations on grounds of protecting genetic diversity. Either way, for these reasons, including climate change in the fisheries management conversation could be perceived as a threat to the livelihoods of commercial and recreational fishers, necessitating careful negotiation and creative problem-solving.

5.3. Participatory modeling in Baltic salmon management

In addition to a better understanding of the problem climate change poses for salmon, this study also demonstrates how stakeholder knowledge and values can be incorporated into problem framing, which should serve as the first step in solving fishery management-related problems (Bardwell, 1991). Including stakeholders at this early stage is especially important in the context of Baltic salmon management because, despite the encouraging outcomes of collaboration under the SAP (1997–2010), salmon management has been a contentious issue since times immemorial (Ignatius et al., 2019). Today, a diverse array of stakeholders at both the national and EU levels, including decision-makers, commercial fishers, recreational fishers, scientists, managers, and environmental non-governmental organizations, must regularly address divisive questions about salmon management (Ignatius and Haapasaari, 2018). The answers to these questions, which are deeply and understandably tied to stakeholders' values and beliefs, tend to clash, leading them to struggle against one another (Ignatius and Haapasaari, 2018). Unfortunately, efforts to reduce such conflicts and give the stakeholders a voice in salmon management have often been imperfect, leaving them feeling embittered and unheard (Ignatius and Haapasaari, 2018; Linke and Jentoft, 2014).

These issues are at least partially responsible for the difficulty in establishing a long-term management plan for Baltic salmon stocks (Linke and Jentoft, 2014) and may therefore also inhibit any future multinational attempts to address the problem climate change poses for salmon management. However, research indicates that providing stakeholders with meaningful opportunities to participate would improve management outcomes. For example, (Haapasaari et al., 2007) found that offering such opportunities to Baltic salmon fishers would improve their commitment to sustainable fishing practices. Therefore, we believe participatory co-management of Baltic salmon is essential and that all relevant stakeholders must be meaningfully included. Further, making certain that problem-solving related to salmon management begins with participatory problem framing, like the process described here, could ensure the problem is considered from all relevant perspectives, thus producing a more holistic knowledge base from which to develop better informed and more mutually acceptable solutions. Problem framing could also help address the conflict between stakeholders, which is particularly relevant in the Baltic salmon management context (Linke and Jentoft, 2014).

5.4. Methodological considerations

This study contains a few limitations worth noting. First, analyzing the large, complex influence diagrams, and elicitation sessions notes via the methods we used here is time-consuming, limiting the feasible number of study participants. Fuzzy cognitive mapping (FCM), a method for creating semi-quantitative cognitive maps similar to the influence diagrams presented here, could provide a solution (Gray et al., 2014, 2015; Olazabal et al., 2018; Özesmi and Özesmi, 2004). FCM provides streamlined methodological options for aggregating stakeholders' conceptual models (Aminpour et al., 2020; Gray et al., 2014; Özesmi and Özesmi, 2004), which are more conducive to including a large number of stakeholders in the problem framing process. FCMs also allow the calculation of several useful metrics, for example, the centrality index, which represents the relative importance of specific concepts within the conceptual model (Gray et al., 2014). Relevant nodes can also be collapsed into themes, helping deconstruct large, complex maps (Olazabal et al., 2018). Further, FCMs can be used to model how changes in one or more of the system variables affect the states of other variables in the model (Aminpour et al., 2020; Olazabal et al., 2018). We believe that like the influence diagrams, FMCs could be easily converted into Bayesian risk assessment models, making FMC and Bayesian modeling compatible partners for natural resource management. Hence, we recommend the FMC approach for further problem framing effort, particularly those including a higher number of stakeholders.

Second, many of the stakeholders did not complete the task of adding effect strengths to their influence diagrams, which is why we have not included this information in the results presented here. Additionally, we suspect the stakeholders may have interpreted the effect strengths in different ways, with some conceptualizing them as degrees of uncertainty and others, as the magnitude of impact. As such for future studies, we suggest facilitators use clear language to explain which information is expected from the stakeholders. We discuss these issues and others related to mental model elicitation in more detail in LaMere et al. (2020).

Third, we believe including all relevant stakeholders is crucial for effective fisheries management (De Young et al., 2008). However, we recognize that representatives from some key stakeholder groups, like commercial fishers, were absent from our problem framing due to the limited reach of our snowball sampling strategy. Therefore, we suggest that as the climate change conversation matures in the Baltic salmon management context, an additional problem-framing study should be conducted, paying special attention to include any groups that were absent from this first round of problem framing.

Lastly, as this portion of the problem framing draws to a close, we should plan a follow-up meeting to discuss the results with the participating stakeholders. Such a meeting would give them a chance to comment and adjust the frame as they see fit. Perhaps most importantly, however, a group meeting would provide them a forum to learn about and discuss the different individual frames collected during this study. Thereby expanding their mental models and allowing them to grow as problem solvers who can approach the problem from multiple perspectives themselves (Bardwell, 1991).

Additional methodological considerations about the mental model elicitation process are presented in greater depth in LaMere et al. (2020).

5.5. Future directions

Based on the results of this study and the concerns expressed in the existing literature (HELCOM, 2011; ICES, 2017, 2019), we assert that while climate change is not the only factor influencing Baltic salmon populations, its effects are nevertheless imminent. As such, we urge ICES to incorporate climate change effects into their existing stock assessment model (Michielsens et al., 2008) expediently to ensure stock projections remain as realistic as possible. The accuracy of these projections is crucial, as they form the basis of ICES' advice to the EU (Kuikka et al., 2014) and thereby enable informed management decisions.

The problem-framing results presented here can assist ICES in determining which concepts and variables to incorporate into their model and the individual stakeholder influence diagrams can serve as alternative hypotheses about the causal dynamics operating within the salmon system. Further, as a next step, stakeholders could build directed acyclic graphs (DAGs), connecting the concepts and variables defined in this study with the relevant aspects of the current stock assessment model, via a process similar to the one described by (Haapasaari et al., 2013). Instead of the effect strengths collected for the influence diagrams presented here, parameterized DAGs include quantified joint probability distributions and define whether two variables are positively or negatively correlated (Jensen and Nielsen, 2007). Owing to these attributes, parameterized DAGs can be integrated into one stock assessment model via Bayesian model averaging (Mäntyniemi et al., 2013). Developing parameterized DAGs would also allow Value of Information (VoI) analysis to be conducted (Mäntyniemi et al., 2009). VoI determines the maximum amount a decision-maker should be willing to pay to obtain more information before making a decision. Therefore, VoI is a central concept in determining what data to collect to assist cost-efficient decision-making.

5.6. Conclusions

In summary, we framed the problem climate change poses for Baltic salmon management by combining the individual perspectives of salmon stakeholders. Through this approach, we identified 15 common themes describing the effects climate change may have on the salmon system, acceptable goals for the system considering climate change, and actions that could be taken to reach those goals. In addition to developing this common ground, problem framing also allowed us to approach the climate change issue from a variety of perspectives to define causal linkages within the system that might have otherwise been missed, explore the context surrounding the issue, and identify potential areas of conflict. We believe participatory problem framing efforts like this are particularly important in the context of contentious natural resource issues, like the salmon fishery, to ensure all relevant stakeholders are meaningfully included in the management process from the outset. We hope this study begins the process of developing the knowledge base necessary for integrating climate change into Baltic salmon management and encourages the use of problem framing in complex fisheries management situations to address emergent threats for the benefit of both the fish and the people who value them.

CRediT authorship contribution statement

Kelsey LaMere: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Project administration, Funding acquisition. **Samu Mäntyniemi:** Conceptualization, Methodology, Writing - review & editing. **Päivi Haapasaari:** Conceptualization, Methodology, Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We would like to offer our sincere thanks to the 11 stakeholders who chose to participate in this research and to Tapani Pakarinen who helped us prepare for the mental model elicitation sessions. We also warmly thank Anna Chysafi for her help in creating Fig. 1 and for her helpful comments on the radar plots.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.140068.

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